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# Continuous Abort Gap Cleaning at RHIC*

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*Abstract*

Since the RHIC Au-Au run in the year 2001 the 200 MHz cavity system was used at storage and a 28 MHz system during injection and acceleration. The rebucketing procedure potentially causes a higher debunching rate of heavy ion beams in addition to amplifying debunching due to other mechanisms. At the end of a four hour store, debunched beam can easily account for more than 50% of the total beam intensity. This effect is even stronger with the achieved high intensities of the RHIC Au-Au run in 2004. A beam abort at the presence of a lot of debunched beam bears the risk of magnet quenching and experimental detector damage due to uncontrolled beam losses. Thus it is desirable to avoid any accumulation of debunched beam from the beginning of each store, in particular to anticipate cases of unscheduled beam aborts due to a system failure. A combination of a fast transverse kickers and the new 2-stage copper collimator system are used to clean the abort gap continuously throughout the store with a repetition rate of 1 Hz. This report gives an overview of the new gap cleaning procedure and the achieved performance.

## INTRODUCTION

While a 28 MHz cavity RF system is used for injection and acceleration in RHIC, thus defining the total number of buckets in RHIC to be 360, a 200 MHz storage system is in use since the 2001 run. An abort gap of approximately 1 $\mu s$ or 30 buckets respectively is needed to make sure that the circulating beam is cleanly removed by the abort system [1]. Any significant beam in this abort gap will not be dumped properly ("dirty dump") and can therefore cause equipment damage, magnet quenches and background peaks associated with potential detector damage for the experiments.

The debunching of heavy ion beam and thus a population of the abort gap is caused by Intra Beam Scattering (IBS) [2] and amplified by the usage of the 200 MHz RF system or RF failures. Debunched beam can account for as much as 50% of the total current. Debunching is a continuous process with varying rates beginning as soon as the energy ramp is finished. Naturally, any species beam can debunch due to RF cavity failures at any time.

## THE PROCEDURE

To attack these problems, the existing hardware of the transverse collimators [3] and the transverse kickers used for the tune measurement system [4] are combined. The Beam in the abort gap is excited transversely by the kickers while the collimators are positioned such that they are the limiting aperture in the rings. The system hardware is described in detail in earlier publications [5] and [6].

Lacking momentum collimators any cleaning procedure has to support two steps:

**(1)** transversely excite the debunched beam (only!) and

**(2)** collimate the excited beam with the transverse scrapers.

In order to excite the debunched beam, the tune meter kickers are timed and triggered such that in place of an occupied bucket beam in the abort gap is excited. The kicker is pulsed for a selectable number of turns per trigger with a repetition rate of 1 or 0.25 Hz. To enhance the cleaning efficiency and increase the transverse amplitude, the frequency has to be as close as possible to the betatron tune of the debunched beam.

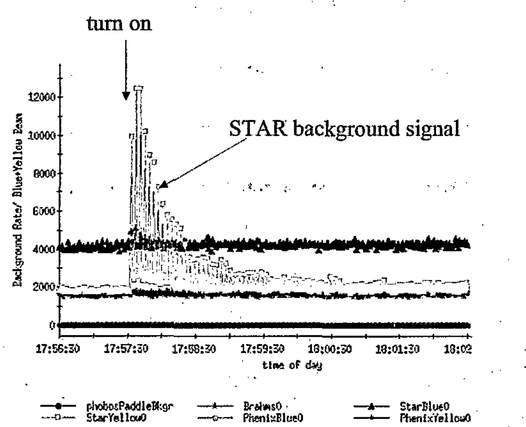


Figure 1: *Background signals from the STAR experiment (BBC) at the time of turn on of the gap cleaning.*

In previous years an application [6] allowed a tune scan in the range of suspect, typically 0.2 to 0.25, where the losses at the collimators are recorded as a function of the kicking frequency in terms of betatron tune. The maximum of this distribution is then used as a set point for the cleaning frequency. This concept is only meaningful if cleaning is done after a certain accumulation time of debunched beam and tunes of debunched and bunched beam had time to diverge. Early in a store while there is practically no difference between the two tunes, the bunched tune can be used simplifying the procedure. In addition, starting the cleaning process early prevents debunched beam accumulation and provides protection from "dirty dumps" at times of unscheduled beam aborts. However, in the past the ex-

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periments were affected by the ongoing cleaning process due to insufficient collimation.

Starting with this years run (FY04) an upgraded conventional 2 stage collimation system was available [6] providing sufficient collimation efficiency to try continuous gap cleaning throughout a store. Fig. 1 shows the background signal from the detectors at a time when cleaning is started with 0.25 Hz and 200 turns/trigger in the yellow ring. At onset, the STAR background signal is increased by a factor 6. After about 2 minutes the background levels are back to normal. This result, obtained early in the FY04 run, encouraged us to proceed with the continuous cleaning approach.

To make sure that the cleaning process is started as early as possible and in every store the RHIC sequencer [8] is used to start the cleaning as soon as the ramp is finished. Just before turn on a regular tune measurement is issued automatically and the cleaning is then started with the appropriate kicking frequency. Since the process is started before debunched beam could accumulate the amount of beam which is excited by the cleaning process should be small and not affect the experiments. In any case, the collimators are typically moved into position a few minutes after the end of the ramp.

## OPERATIONAL EXPERIENCE

In general, the continuous cleaning was successful and very efficient. There was no additional background reported by experiments due to it. Fig. 2 shows one store, 4471 on Feb. 06 2004, with gap cleaning active in the blue but inactive in the yellow ring. When the debunched beam exceeds the limit of 5 $10^9$ [6] around 3:30 am, the "old style" cleaning process [6] is started. The difference of the accumulation rate of the two beams is obvious. There is practically no debunching in blue (0.12 $10^9$ ions/h) but approximately 1.25 $10^9$ ions/h debunching in yellow, yielding an improvement by a factor of 10 due to the cleaning.

The cleaning process can also be interrupted momentarily for various reasons such as operator failure, hardware or controls software failure or the need for continuous tune measurements. Any interruption is generally risky since debunched beam will accumulate while the process is stopped. The increased amount of debunched beam will potentially cause high backgrounds at restart. It might even cause the loss of the store due to peaks in some loss monitor signals, high enough to trigger a beam abort. Fig. 3 shows an event of a short term cleaning interruption. To allow frequent tune measurements the cleaning procedure was stopped for about 5 minutes during store 4293 on Jan 16, 2004. The turn off and turn on times are indicated by the vertical lines. The top panel depicts the beam loss rate for the two beams. Typical values at store were around 2.5 %/h without cleaning. The high loss rate ($\geq$ 15 %/h) for the blue beam before 14:18 is mainly due to bad liftetime because of an orbit distortion in the blue ring. When the cleaning is restarted 5 minutes later the loss rate jumps

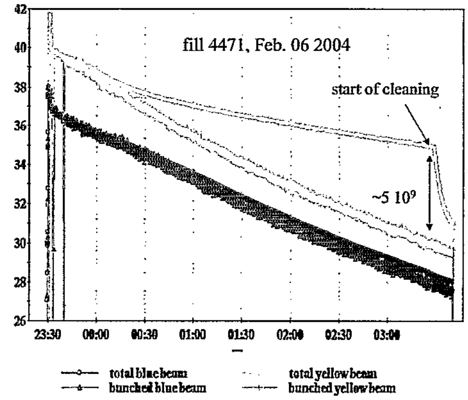


Figure 2: *Total and bunched beam currents as a function of time during store 4471. Blue cleaning is active, yellow cleaning is started at 3:30 am.*

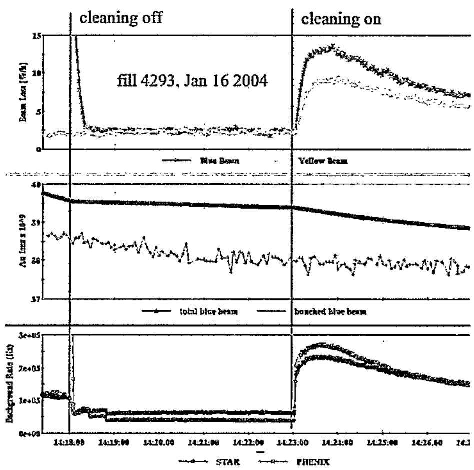


Figure 3: *Top graph: Blue and yellow beam loss evolution. Center graph: Total and bunched blue beam as a function of time. Bottom graph: Background rates arising from the blue beam in the STAR and PHENIX detectors during the same time.*

up to about 14 %/h and 10 %/h for the blue and yellow ring respectively. This corresponds to an increase by about x4-x6. Experimental backgrounds (bottom panel) increase by about x2-x3 compared to the levels before the cleaning is stopped and by about x5 compared to the levels while cleaning is off. Note that the higher levels before the cleaning is stopped were mostly due to the bad blue beam lifetime at the time.

## LIMITATIONS

Even with the gap cleaning active there still remains an effective accumulation rate of the debunched beam. Fig. 4 shows this accumulation. In both presented stores the gap

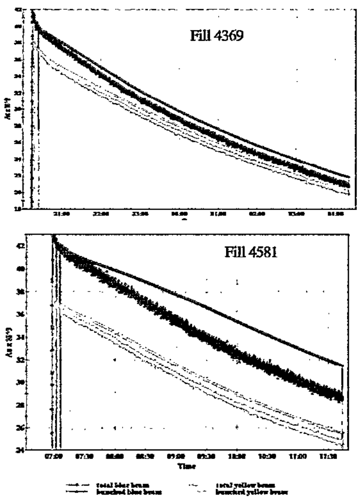


Figure 4: *Total and bunched beam currents as a function of time in two stores. Top: 61x61 bunch pattern, bottom: 45x45 pattern.*

cleaning is active. The actual accumulation rate depends on a combination of bunch current $I_b$, longitudinal and transverse emittances. In addition there might be other parameters such as orbits distortions or RF configuration which could increase beam scraping or enhance debunching respectively. Tab. 1 compares the two shown examples. Only the bunch current is taken into account. Seven more stores

| fill | length [h] | $I_b$ [ $10^9$] | deb. rate [ $10^9$/h] |
|---|---|---|---|
| 4369 | 8 | 1 | 0.12 |
| 4581 | 4.6 | 3 | 0.65 |

Table 1: *Comparison of two stores during the RHIC FY04 Au run.*

were analyzed (arbitrarily selected) and the result is shown in Fig. 5. A linear and a parabolic fit is superimposed. No distinction between the two based on the presented data can be made. However, the dependence of the accumulation rate on the bunch current is quite noticeable. Based on this data and assuming a linear dependence, the accumulated debunched beam could reach 5 $10^9$ ions after 4 hours of store. This would correspond to $I_b \geq 1.4\ 10^9$ ions. Once this limit is reached the existing gap cleaning system will not be able to keep the amount of debunched beam under the limit. In FY04 RHIC achieved a maximum of $I_b = 1.1\ 10^9$ ions.

## CONCLUSION

Continuous abort gap cleaning proved itself very effective and efficient. The risk of magnet quenches due to involuntary beam aborts at the presence of more than 5 $10^9$ ions of debunched beam basically disappears. At RHIC cleaning was typically used with 290 turns/trigger and a

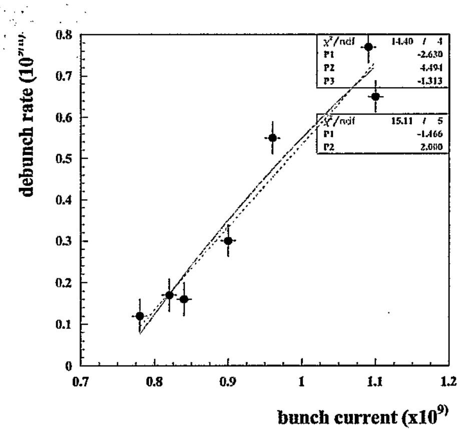


Figure 5: *The accumulation rate of debunched beam with gap cleaning active as a function of $I_b$.*

trigger rate of 1 Hz. The start of the procedure was automated to make sure that it is started as soon as the ramp is finished and debunching begins. If started early enough in a store there is no noticeable background increase in the experimental backgrounds. Continuous gap cleaning reduces the rate by which debunched beam accumulates by about x10 if compared to a situation with no gap cleaning at all. To avoid experimental background any interruption of the cleaning process should be avoided. Even a few minutes of interruption can cause background increases by x5. Once bunch currents of 1.4 $10^9$ ions and more are achieved in RHIC the existing gap cleaning system is not sufficient anymore.

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